THE RELATIONSHIP BETWEEN URBAN SPRAWL AND DISASTER RESILIENCE: AN EXPLORATORY STUDY

A Thesis

by

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ABSTRACT

In the wake of ever increasing numbers of natural disasters around the world, further exacerbated by climate change and our growing alarm and vulnerability to them, the notion of resilience has become an important topic within disaster research. Studies have shown an important influence of the built environment, such as urban sprawl, on disaster resilience. This study is an attempt to address the growing danger we face from natural disasters, by examining the role of urban sprawl with respect to community resilience. It identifies indicators and measurements of urban sprawl and disaster resilience with the goal of deriving relationship between the two. Furthermore, the study inquires whether such a relationship varies across different regions in the United States.

Using the data from 994 counties in the United States, this study examines associations between urban sprawl and disaster resilience, using correlation analyses (i.e. Pearson's R, analysis of variance (ANOVA), and regression analysis)

The result shows a negative relationship between urban sprawl and disaster resilience, which means that disaster resilience is higher in counties with more compact development patterns. Also, the Northeast region was shown to have a stronger relationship than the West, suggesting that the relationship between urban sprawl and disaster resilience varies across regions.

DEDICATION

I dedicate this thesis to my family, my grandmother, my father, my mother, my younger brother, and my sister in law. I will be forever obliged by your unending support during my Master's program. Thank you for being part of my life no matter what.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1. Research Background

In response to the growing threat of natural disasters, the issue of disaster resilience has become an important part of disaster planning research (Chamindi et al., 2014). The importance of resilience is well known, especially with regards to adaptive capacity of a community to return to its previous state before the damage. On the other hand, limited empirical evidence exists on the influence of built environment on community resilience from disaster (Carpenter, 2013). Better understanding of resilience is crucial for creating sustainable and safe communities.

Previous studies have identified multiple factors influencing or associated with disaster resilience. First of all, it has been widely acknowledged that the built environment influences disaster resilience in multiple ways. Some studies have indicated that mix-use neighborhoods or walkable communities encourage social capital and place-attachment by enhancing interactions among the neighbors, because such neighborhoods often have various places to support social networking opportunities, e.g., parks, churches, local shops, and schools (Talen, 2002; Leyden, 2003). A few other studies have shown that social network can be promoted by physical structures and it contributes to disaster recovery in flood-damaged areas (Sherraden et al., 1997; Hemer, 2002).

Other studies have argued that the cost effectiveness of built environments, such as public services and transportation infrastructure, will be enhanced by having more compact areas rather than sprawl areas in which service infrastructure construction tends to cost more (Carruthers, 2003; Lambert et al., 2009).

The United States have gone through a swift shift in its housing market. With the development of high-speed roads that lead to suburban and rural areas, many mid/upper-class families have opted for residing in a suburban area that provides safer and cleaner housing, parks, schools, etc. (Ciscel, 2001; Glaeser & Kahn, 2004). The word “sprawl” or “urban sprawl” was coined for urban development. Sprawl has been associated with “unplanned or haphazard development” (Ewing et al, 2014). Some studies have argued that there are negative externalities in big cities and metropolitan areas not associated with sprawl, such as increased pollution from vehicle emission (Glaser & Kahn, 2004). There are also health-related concerns about sprawling areas, as they may suffer from higher prevalence of obesity, fatalities and injuries from traffic crashes (Lambert & Meyer 2006), delay in emergency response (Trowbrige et al., 2009; Katirai, 2011), as well as environment problems such as air pollution and water drainage problem during/after a storm (Club, 1998). With regards to the environment problems, studies have shown a notable impact of the built environment including features related to urban sprawl, on disaster resilience (Carpenter, 2013; Lambert et al., 2015). However, the roles or concepts of urban sprawl have not been comprehensively captured in most of these studies focusing on the built environmental factors. Only a handful of these studies have shown that the built environmental features related to urban sprawl, such as accessibility and walkability, are effective in creating resilient communities (Mahriyar & Rho, 2014; Freitag et al., 2014). Therefore, this study aims to contribute to this area of research by more explicitly and comprehensively measuring urban sprawl with validated multi-dimensional indicators, and examining its link with disaster resilience.

1.2. Research Objectives and Hypotheses

The purpose of this study is to identify valid indicators to measure urban sprawl and disaster resilience, and to examine the potential relationship between sprawl and disaster resilience. The specific objectives of this research are to:

- Examine the relationship between urban sprawl and disaster resilience
- Examine the relationship between urban sprawl and each of the individual disaster resilience indicators
- Explore the variations in the relationship urban sprawl and disaster resilience across different geographic regions in the United States

Relevant study hypotheses are:

- Disaster resilience will be higher in compact areas than in sprawling areas.
- Individual disaster resilience indicators will have negative relationships with urban sprawl.
- Disaster resilience-sprawl relationships will differ across different geographic regions in the United States.

2. LITERATURE REVIEW

There are three sections in this literature review: The first section is devoted to discussing the theoretical background, definitions and measures of urban sprawl. The second section covers definitions and measurements of disaster resilience. The last section discusses the knowledge gap found from the literature review.

2.1. Urban Sprawl

2.1.1. Theoretical Background of Urban Sprawl

Urban sprawl refers to the spread of urban development into undeveloped areas near a city (Berrigan et al., 2014). The entire nation is gradually coming to be aware of the important relationship of urban sprawl with other problems such as air pollution, traffic accidents, degradation of scenic areas, and obesity problems. In order to address these issues, we need to understand the features and outcomes associated with urban sprawl.

William H. Whyte was the first person who used the term “urban sprawl” in 1985. Sprawl has since been recognized an important issue in planning and other relevant fields (Glaser & Kahn, 2004). First, several studies have been conducted addressing the causes and impacts of sprawl. According to Burchfield et al. (2006), the causes of sprawl can be found in uncertainty about metropolitan growth, decentralized employment, ground water avidity, and early public transport infrastructure. Also, concerning the impacts of sprawl, Orfield (1999) showed negative impacts of urban sprawl, including the concentration of poverty and the decline of economic distribution. He focused on the example of Minneapolis–Saint Paul, and presented useful strategies for improving schools and numerous other projects in addition to protecting the environment and quality of life. He maintained that higher spending on schools in areas of concentrated poverty is pointless and we need a redistribution moving some of the poor to the suburbs and some of the wealthy downtown by building affordable housing in the suburbs. Also he argued that competition among localities drives the desire for less dense construction in hopes that it will produce more tax revenue than it produces demand for services.

Likewise, Katirai (2011) further identified the negative impacts of sprawl. He analyzed fire protection using response times by socio economic status (SES). Response times was used as a dependent variable and urban sprawl variables were used as an independent variable. The result indicated that urban sprawl have a negative influence on response times, such as delays in EMS (emergency medical service). In addition, Club (1998) discussed the negative impacts of sprawl through literature review, such as traffic congestion, longer commutes time, worsening air & water pollution, and increasing flooding.

In a recent study, Berrigan et al. (2014) analyzed the relationship between urban sprawl and cancer morality. The results showed that cancer mortality rates were lower in sprawling areas and they also found statistically significant relationship ($p < 0.05$) between regions (census divisions) and urban sprawl.

Despite the relatively solid body of empirical studies on the impacts of or factors contributing to sprawl, the potential relationship between urban sprawl and disaster resilience, has not been fully explored.

2.1.2. Measure of Urban Sprawl

Recently, academics, journalists, and activists have tried to pin down sprawl. Various measurement methods have been employed to quantify urban sprawl. One of the popularly used ways to measure urban sprawl index was developed by the USA Today[1] (Ewing et al., 2003). The USA Today index allocated a value for each of the 271 metropolitan areas based on two measurements: The proportion of the population who lives in the urbanized area out of metropolitan area[2], and the change in this proportion from 1990 to 1999.

The strength of this method is the easy interpretation of its result[3]. However, it also has its drawbacks: it relies on the proportion of the population who live in the urbanized area. This proportion as the only indicator of urban sprawl presents challenges in distinguishing high-density urban developments from low-density suburban developments. It is difficult to capture all of the inherent characteristics of sprawl with only one or two indicators (Ewing et al., 2003).

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[1] http://usatoday30.usatoday.com/news/sprawl

[2] Urbanized area is defined by the Census Bureau which have 1,000 or more population per sq. /mi.

[3] "Metropolitan areas were ranked 1 through 271 on each measurement with lower numbers representing less sprawl. The two rankings were summed to produce each metro area's sprawl score. The highest possible score was 542, the lowest 2 (page 25, Ewing et al., 2003)."

The Sierra Club published the ranking of the United States metropolitan areas with regards to their degree of sprawl (Glaser & Kahn, 2004). They described sprawl as "low-density in urban development that divides the residential area from the places of shopping, work, recreation, and education, etc., thereby requiring use of transportation, in particular individual-owned cars." Their sprawl ranking was based on their measure capturing: population movement from urban area to suburban area, wasting of time in traffic jam, open space area, and growth of population.

In the article 'Wrestling Sprawl to the Ground: Defining and Measuring an Elusive Concept,' they considered multi-level approaches to properly measure urban sprawl. Galster et al. (2001) came up with a more sophisticated and multifaceted sprawl index than those previously developed. They characterized sprawl based on seven dimensions: mixed use, concentration, continuity, density, centrality, clustering, and proximity. For measuring these dimensions, mixed use for example was captured as the rate of different land uses in the same urbanized area. To measure centrality, they used the residential units per square mile. They calculated nonresidential or residential units which is located in the central business area. However, they have a limitation on applicability of their index to various regions.

Ewing et al. (2003, 2014) have also come up with an urban sprawl index that measures various aspects of factors that involve multi-domain approaches of urban sprawl. Their urban sprawl index focuses on the four components of urban form[4]: street accessibility, development density, activity centering, and land use mix. While some of

[4] See the Chapter 3.4.1 for examples of the specific measures used for each component.

the popular measures or indicators of sprawl relied on one or a small number of variables to capture urban sprawl, their study recognizes that urban sprawl is a complex and multi-dimensional phenomena, and it requires multi-level or multi-domain approaches to appropriately capture urban sprawl. Also, another advantage of their urban sprawl index is its availability for diverse regions.

In addition to the measures to quantify urban sprawl, the spatial unit and extent to study urban sprawl are also important. There can be multiple geographic scales e.g., national level, sub-national level, or neighborhood level. Most studies of urban sprawl have focused on sub-national levels, such as metropolitan area, urbanized area, and county as their spatial boundaries. For example, in case of the USA Today and the Sierra Club, they used the metropolitan area as their unit of analysis and ranked the United States metropolitan areas based on the degree of urban sprawl. Galster et al. (2001) and Song & Zenou (2006) used the urbanized area as their unit of analysis to measure urban sprawl. Also, according to Berrigan et al. (2014), the geographic extent of their analysis covered urban and suburban counties in the United States, arguing that macro-scale characteristic such as county level is more suitable to measure urban sprawl rather than micro-scale. As indicated above, many case studies have focused on macro-scale characteristics because the spatial boundaries of sprawl area are far from clear and it is appropriate to measure sprawl at the macro scale.

In this thesis study, I used the urban sprawl index developed by Ewing & Hanmidi (2014b) that enables a multifaceted measurement of urban sprawl needed to assess urban sprawl comprehensively.

2.2. Disaster Resilience

2.2.1. Definition of Disaster Resilience

According to Timmerman (1981), “resilience is the measure of a system's or part of the system's capacity to absorb and recover from an occurrence of a hazardous event.” He describes the concept of resilience as an approach for recovery from the damaging event. Since Timmerman, different definitions of resilience have appeared. These definitions were published in the natural disaster literature. The definitions have involved to incorporate the compound multidisciplinary nature of the issue (Klein et al., 2003). It is difficult to find a common ground on the definition of resilience from the natural disaster literature. When applied to groups of people and communities, the definition of resilience provides that resilience is directly related to the capability or ability of individuals and communities to deal with the contrary effects of a disaster impact (Burton, 2012).

2.2.2. Measure of Disaster Resilience

The measurement of disaster resilience requires a complex procedure, because of the dynamic interdependence of residents, communities, and built environment. Numerous measurements have been proposed and used to capture disaster resilience in the literature (Table 1), with no agreed upon standard (e.g. Cutter et al., 2010; Kafle, 2012; & Kusumastuti et al., 2014) and Table 2 shows the specific measurement of disaster resilience.

Most resilience frameworks are disposed to focus on increasing resilience. Also, many frameworks include a limited number of dimensions that fail to provide a comprehensive view of the concept (Cutter et al., 2010). Most of the previous studies on this topic have focused on the creation of indicators for measuring disaster resilience. Some similarities are found among the measurements for disaster resilience, which often include community, infrastructure, institutional, social, and economic sub-domains (Chang & Shinozuka, 2004; Norris et al., 2008; Cutter et al., 2010). For example, the community domain has been often measured by health insurance coverage, number of physicians, and place attachment. The infrastructure domain has been measured by transportation network, residential house type and age, and commercial establishment. The institutional domain has been commonly measured by the presence of hazard mitigation plans and emergency response plan, and by hazard experiences (Norris et al., 2008).

Chang & Shinozuka (2004) studied the advancement in disaster resilience measures and framework. Their framework entailed diverse aspects of resilience, including economic social organizational and technical aspects[5]. They offered the resilience framework for guiding disaster preparedness and mitigation by comparing seismic retrofit processes between two case studies.

[5] Table 2 shows the specific measurement of resilience.

Cutter et al. (2008) also attempted to perform a disaster resilience analysis. They came up with the disaster resilience of place (DROP) model to analyze the disaster resilience and provided the indicators for measurement including social, infrastructure, economic, and community capital sections. The DROP model estimates the relationship between resilience and disaster vulnerability based on a series of processes or methods involving empirical testing, quantitative analysis, addressing the problem in real space using field testing and antecedent condition[6] because they focus on the inherent resilience.

In a study conducted by Cutter et al. (2010), the DROP model was applied to counties within the Southeast region in the United States and provided a methodology and disaster indicators for measuring resilience. Their results showed that the level of disaster resilience vary in different areas and rural counties usually have lower disaster resilience than metropolitan areas.

[6] "Antecedent conditions represent a temporary state within dynamic natural and social systems that precedes and influences the onset and magnitude of a hazard and its consequences" (Crozier et al., 2013).

Table 1. Measurements of Disaster Resilience

Index	Domain	Unit of Analysis	Data Source	Stage of Development
Baseline Resilience Indicators for Communities (BRIC)	ecological, social, economic, infrastructure, Institutional, competencies	communities	secondary data only	IMPLEMENTATION; partially in South Carolina, USA
Analysis (CoBRA)	survival and livelihood protection threshold; physical, human, financial, natural and social	households (for meta-indicator), Communities	primary data collection in combination with secondary data	POTENTIAL INDICATORS IDENTIFIED
Resilience Capacity Index (RCI)	economic, socio-demographic, community connectivity capacities	communities in U.S.	secondary data only	IMPLEMENTATION: data for USA
Tsunami Recovery Impact Assessment and Monitoring System (TRIAMS)	vital needs, basic social services, infrastructure, livelihoods	Indonesia, Sri Lanka, Maldives, Thailand	secondary and primary data; qualitative data for triangulation	IMPLEMENTATION; (in Indonesia, Sri Lanka, Maldives, Thailand)
ResilUS	recovery module, loss estimation module	communities in U.S.	secondary data only	IMPLEMENTATION; prototyping in 3 study areas
Minimum characteristics of NRRC	institutional, information, assessments, teams, plans, funding, infrastructure, warning systems	communities in Nepal	primary data collection required in most cases	POTENTIAL INDICATORS IDENTIFIED
DRLA/UEH Evaluation Resilience Framework for Haiti	wealth, debt and credit, coping behaviors, human capital, protection and security, community networks, and psychosocial status	households	primary data (surveys & focus groups)	IMPLEMENTATION (in Haiti)
Livelihoods Change Over Time (LCOT)	three types of analysis: a) household welfare over time, b) food security dynamics, c) poverty traps	households	secondary and primary data (four rounds of a household survey over two years)	IMPLEMENTATION (in selected areas)
FAO Resilience Tool	assets, income and food access, access to basic services, social safety, adaptive capacity, stability	communities	secondary data only	IMPLEMENTATION (in selected areas)
PEOPLES Resilience Framework	population & demographics, environmental/ ecosystem, services, infrastructure, lifestyle, economic, social-cultural	communities	secondary data only	POTENTIAL INDICATORS IDENTIFIED
Indonesia Disaster Recovery Index (DRI)	22 recovery variables	communities in Indonesia	primary data (household surveys)	IMPLEMENTATION (in Indonesia)

Source: Winderl, T. (2014) Disaster resilience measurement, p23.

Table 2. Specific Measurement of Disaster Resilience

Category	Sub-component	Descriptions	Source
Social	Demography	Percent population with elderly age	1, 5, 7
		Percent population that are literate	1, 2
		Percent population without disabilities	2, 9
		Percent population living in disaster-prone area	2, 9
		Percent population with college or more	1, 2
		Percent population with Hispanic/Latino	1, 2
		Percent population with speaking English as a first language	1, 5
	Social Services	Number of volunteers	1, 2
		Number of NGOs	1
	Social Preparedness	Percent population with vehicle	1, 5
		Percent population with telephone service	3, 4
Economic	Asset	Percent homeownership	1, 5
		Median house income	1, 5
		Percent population living in poverty	1, 2
		Tropical livestock unit equivalent to 250kg	2. 9
		Average per person daily income	2. 9
		Percent wealth generation	1, 2, 9
	Business contribution	Percent population with employed population	5
		Percent population with female labor	3, 7
		Percent population not employed in farming, fishing, and extractive industries	3, 7
Infrastructure	Building & housing	Percent housing units that are not mobile home	3, 7
		Percent housing units built after 2000	3, 7
		Percent housing units with brick walls	3, 7
		Number of building permits for new construction	3, 7
	Transportation network	The length of road per square mi.	2, 7
		Number of transportation access to the area	2, 4, 6
	Evacuation potential	Number of highway bridges	2, 8
		Arterial miles per square mi.	2, 8
	Shelter capacity	Percent vacant rental units	1, 4
		Number of hospital beds per 100,000 population	1, 2
		Number of public schools per square mi.	1, 2

Table 2. Continued

Category	Sub-component	Descriptions	Source
Institutional	Disaster damage plan	Percent municipal's budget for disaster management	2
		Existence of municipal's regulation for disaster response	2
		Number of municipal expenditure (fire, police, emergency service as %)	2
	Disaster mitigation plan	Number of hazard mitigation plan	2
		Number of disaster declarations	1, 2
		Number of Storm Ready participation	1, 4, 6
		Percent housing units covered by NFIP policies	2, 6
	Politic fragmentation	Number of governments and special districts	1, 4
		Percent population covered by Citizen Crops programs	1, 4
Community	Place attachment	Percent population born in state that still reside	1, 6, 7
		Net international migration	2, 8
	Political engagement	Number of voter in the election	2, 8
	Social capital	Number of religious adherents per 10,000 population	1, 6
		Number of social advocacy organization per 10,000 population	1, 6
		Number of civic organization per 10,000 population	2
		Percent population employed in creative class occupations	1, 8
Ecological	Land area	Percent land area in 100-year flood plan	1, 8
		Percent land area subject SLR	1, 4
		Percent green space and undisturbed land	4, 8
		Percent urban area	2, 6
		Percent forested land cover (wildfire potential)	2, 6
	Soil & wetland	Percent with hydric soil (liquefaction)	2, 6
		Percent Wetlands acreage and loss	2, 6
		Percent soil erosion	2, 6

1. Cutter et al. (2010), 2. Cutter et al. (2008), 3. Sherrieb et al. (2012), 4. Norris et al. (2008), 5. Morrow (2008), 6. Tierney (2009), 7. Colten et al. (2008), 8. Carpenter (2015)

2.3. Urban Sprawl and Disaster Resilience

In this section, evidence supporting the relationship between urban sprawl and disaster resilience is discussed. Concepts directly relevant to urban sprawl, such as smart growth and compact city have been also included in the review.

First, the relationship between built environments and disaster resilience has been suggested in the literature. Manyena (2014) argued that the concept of resilience is increasingly important part of disaster problems, and this concept is important for increasing adaptive capacity which makes community resilient. Meanwhile, Carpenter (2015) argued that built environments have an influence on social networks. This social concept can be related to resilience and disaster vulnerability. Thus, built environments can affect disaster resilience. Besides, Wang et al. (2012), Chamindi et al. (2014), and Lizarralde et al. (2015) showed that several empirical studies suggested a potential relationship between the built environment and disaster resilience. Ewing et al. (2014) mentioned urban sprawl as built environmental phenomena.

Second, a relatively small number of studies have investigated the relationship between urban sprawl and disaster resilience explicitly. Lambert et al. (2015) studied the influence of sprawl on the Federal Emergency Management Agency (FEMA) relief spending in Metropolitan areas. They used “expenditures per capita per county on infrastructure public assistance” as a dependent variable and the factors such as the number of firefighters per capita per county, median year of all housing structure built per county, weather severity index, and sprawl index as the independent variables.

They found that urban sprawl has an influence on the level of FEMA's public spending on infrastructure. One of the limitations of this research is that for estimating disaster resilience, they only used the public spending on infrastructure, and thus its measurement does not capture the characteristics of disaster resilience completely.

Thirdly, the concept of compact city has also been studied for its potential links with disaster resilience. Bansal et al. (2012) conducted a theatrical study for association of compact developments and disaster management focusing on the sustainability and resilience of the community. They did a literature review for decreasing in urban heat island, effective emergency response management, mitigation plan for water-related disasters, and smart growth principles for increasing urban resilience. This paper attempted to find a role of compact development and its influence on disaster and tried to verify the relationship between sustainable community and disaster resilience plan for the future. Finally, they argued that compact development will reduce disaster risks and make community sustainable by decreasing public service and infrastructure costs, providing saving on utilities, garbage collection, sewage, and school transportation.

The study by Dempsey & Jenks (2016) argued that the compact city is advantageous to alleviate global warming by minimizing physical urban structure and resources. Also, they argued that sprawling area may be more difficult to project against water-related disaster than compact areas. Thus, the aforementioned studies suggested a potential association between sustainable development strategies and disaster resilience.

Fourth, this study reviewed previous studies on the association between the concept of smart growth and disaster resilience. Taniguchi et al. (2005) used smart growth concept such as SLIM City (Smart Layout Indicators to Materialize Compact City) to assess compact urban layout focusing on the management of land recycle and the prevention of flood. They used SLIM City indicators including car ownership, aging rate, total trip length, trip generation, and common segmentation for trip makers to evaluate compact city layouts and compared these with flood disaster damage. Their results showed that compact urban forms such as SLIM City provide more information for flood prevention and they have a manageable and simple system against natural disasters. They argued that compact city can provide more information about flood prevention and the basic evacuation indicators which are provided in compact area.

Also, Coaffee (2008) studied the link between risk society and environmentally smart cities. He suggests sustainable design considerations and strategies for security to establish safety society from disaster for access control, surveillance, and blast protection categories.

Lastly, contrary to the studies above, some researchers argue for the negative relationship between urban sprawl and disaster resilience. Song et al. (2009) argue that urban compactness, such as New Urbanism development, has a negative influence on urban flood vulnerability. Their results show that a large number of compact developments are exposed to disasters and they are vulnerable to water-related disaster.

While studies targeting urban sprawl explicitly are limited, many studies have used similar concepts such as smart growth and urban compactness to assess the potential associations with disaster resilience. Those studies have provided helpful theoretical foundations for establishing the relationship urban sprawl and disaster resilience (Taniguchi et al., 2005; Bansal et al., 2012; Wang et al., 2012; Lambert et al., 2013; Manyena, 2014; Chamindi et al., 2014; Carpenter, 2015).

Some researchers have argued that through the factors, such as mixed use and walkable space that are only partially related to sprawl, we can improve community resilience (Talen, 2002; Leyden, 2003; Burton, 2012). Other studies claim that there is a positive correlation between disaster resilience and cost effectiveness due to efficient urban infrastructure (Carruthers, 2003; Lambert et al., 2009).

Therefore, this research attempts to further verify the sprawl-resilience relationship through an empirical study.

2.4. Gaps in the Literature

Through the review of pertinent literature, this study found the knowledge gap in several areas. First, regarding the relationship between urban sprawl and disaster resilience, the research hitherto has shown conflicting or inconsistent relationships. While some argue that urban compactness has a negative influence on disaster resilience, others claim of their positive correlation. This study attempts to find their relationship through an empirical method. It also employs concepts relevant to urban sprawl, such as smart growth, compact city, and new urbanism, in order to establish the theoretical ground of their potential associations with disaster resilience.

Second, even though many studies addressed the relationship between built environment and disaster resilience, only a few studied urban sprawl explicitly. To my knowledge, no empirical studies explicitly and directly examined the relationship between urban sprawl and disaster resilience, with an exception of one report by Lambert et al. (2015). They used the expenditure on infrastructure as a dependent variable to measure disaster resilience. It has a limitation as it did not capture all the characteristics of resilience comprehensively. Also, he analyzed the link between urban sprawl (compactness) and post-disaster resilience which is related to damage. However, I focus on the antecedent condition using the DROP model instead of a damage based model because measuring disaster resilience through post-disaster damage is highly related to a damaged area where a disaster happened rather than an urban sprawl.

3. RESEARCH DESIGN AND METHODS

3.1. Conceptual Framework

This study is to ascertain valid indicators to measure urban sprawl and disaster resilience, and to verify the potential relationship between sprawl and disaster resilience. The study will test the hypotheses that disaster resilience will be higher in compact area than in sprawling area, and disaster resilience-sprawl relationship will differ across different regions in the United States Sprawl has been linked with haphazard or unplanned developments (Ewing et al., 2014). Some studies have argued that urban sprawl creates negative externalities in big cities including environment problems, such as air pollution and water drainage problem during/after a storm (Club, 1998).

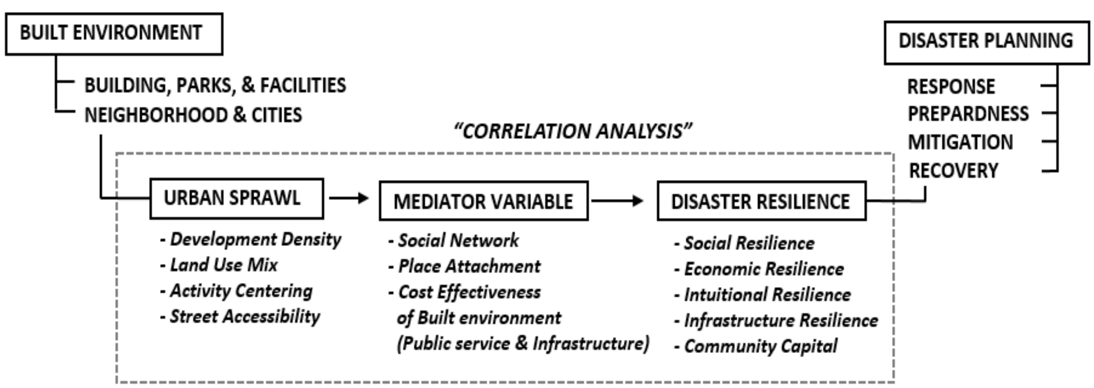

Figure 1. Conceptual Framework

Some studies have supported their potential relationship between built environment and disaster resilience. Carpenter (2015) showed that built environments have an influence on social networks and this social concept can be related to resilience and disaster vulnerability. Also, Lizarralde et al. (2015) showed empirical studies, which suggested a potential relationship between the built environment and disaster resilience. Bansal et al. (2012) performed a theatrical overview about compact developments for their disaster management tool focusing on the sustainability and resilience of the community. They showed that sustainability and resilience of the community can be achieved with the concept of smart growth focusing on compact development. The concept of smart growth also has an influence on disaster resilience. Tanuguchi et al. (2004) used smart growth concept to assess compact urban layout focusing on the management of land recycle and the prevention of flood. Their results showed that smart growth provide more information for flood prevention and they have a manageable and simple system against natural disasters.

According to Hermer (2002), Talen (2002), and Leyden (2003), walkable communities or mix-use neighborhoods encourage social capital and place-attachment by enhancing interactions among the neighbors. These social networks contribute to increase disaster recovery. Other researchers have shown that the cost effectiveness of built environments, such as public services and transportation infrastructure, have an influence on disaster resilience. Compact areas are more cost effective than sprawl areas (Carruthers, 2003; Lambert et al., 2009). While many studies mention the relationship between built environment and disaster resilience, only a few mention urban sprawl. Thus, this study can be an exploratory study to analyze the potential relationship between urban sprawl and disaster resilience.

3.2. Research Process

The research process used to examine the relationship between urban sprawl and disaster resilience in this study is shown in the chart below (Figure 2).

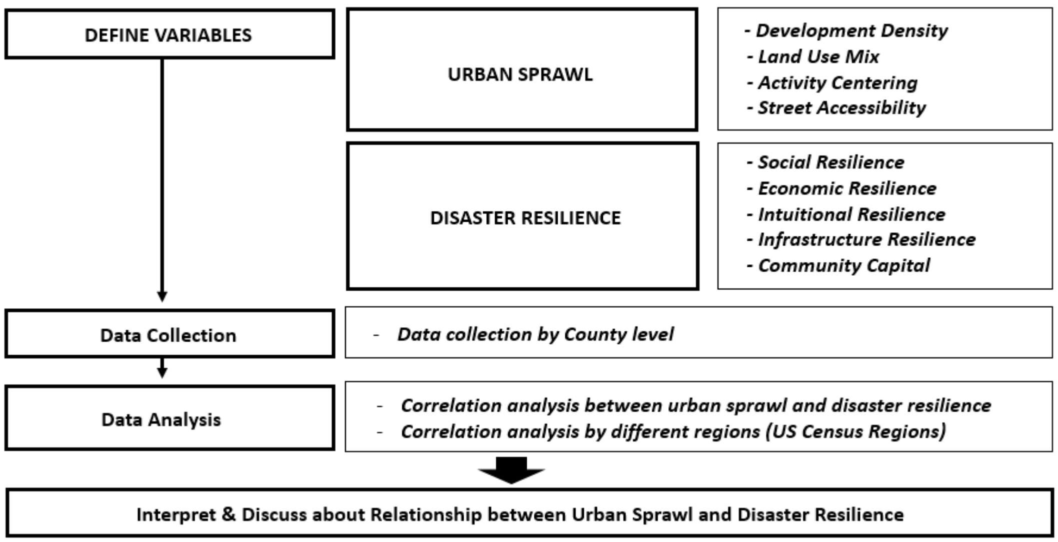

Figure 2. Overview of Research Process

There are two steps for the measurements: the urban sprawl measurement (using urban sprawl index) and the disaster resilience measurement (using resilience indicators). For urban sprawl measurement, this study uses the urban sprawl Index developed by Ewing & Hanmidi (2014) which focuses on the four main components: development density, street accessibility, activity centering, and land use mix. Higher urban sprawl value represents less sprawling urban form, such as compact area[7].

[7] See the Chapter 3.4.2. below

For disaster resilience measurement, for disaster resilience the study uses the inherent resilience component in DROP model (the disaster resilience of place) by Cutter et al. (2010). The disaster resilience indicators were selected through the literature review[8]. The disaster resilience indicators used in this study have five sub-components: social, economic, infrastructural, institutional, and community factors. Each of these components contains three to seven indicators adding up to a total of 25 indicators (Table 4).

After measuring each indicator, they were normalized with Min-Max normalization for combining every indicator. Min-Max normalization is the process of taking data measured in different units and transforming them to a value between zero and one-hundred (equation 1). These variables were summed in equal weight in the overall index. ei, the normalized value for variable E in the ith row is derived as below: (Emin = the minimum value for variable E; Emax = the maximum value for variable E):

$$Normailzed\_Data(e_i) = \frac{e_i - E_{\min}}{E_{\max} - E_{\min}} \text{ X } 100 \qquad (1)$$

Lastly, the study uses correlation analyses to analyze the relationship between urban sprawl and disaster resilience using the data gathered and prepared in the previous processes. There are two steps in the correlations analysis: First, the correlation between

[8] See the Chapter 3.4.1. below

urban sprawl and disaster resilience is examined using correlation analysis, analysis of variance (ANOVA), and regression analysis. Second, in order to explore the potential differences in the sprawl-resilience relationship across different regions, this study used Census Regions[9] to carry out separate correlation analyses.

3.3. The Unit of Analysis

In analyzing the relationship between urban sprawl and disaster resilience, it is important to consider the geographic scale/extent. There can be multiple geographic scales for measuring disaster resilience, e.g., national level, sub-national level, or neighborhood level. This study is conducted at the county level (the sub-national level) rather than the smaller neighborhood level. Urban sprawl is an urban development that spreads out into an undeveloped area near a city. Thus, it is appropriate to measure urban sprawl at the macro scale such as the county level (Ewing & Hanmidi, 2014).

[9] "Census Regions are groupings of states and the District of Columbia that subdivide the United States for the presentation of census data. There are four census regions: Northeast, Midwest, South, and West" (www.census.gov).

3.4. Study Area

The study covers 994 counties in the United States including most of the metropolitan statistical areas. Out of 3,144 counties in the nation, 994 were chosen based on the following reasons[10].

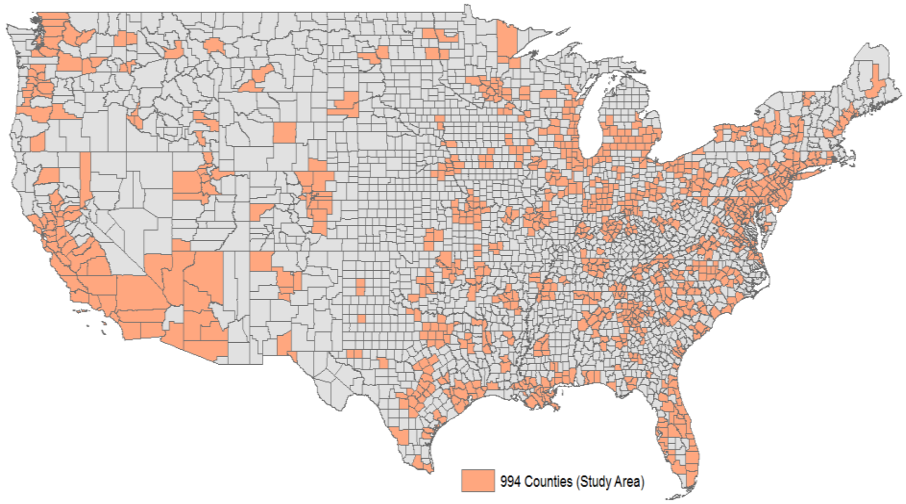

Figure 3. Study Area

First, this study focused on the metropolitan areas because, according to Census Data 2014, more than 80% of the US population lived in metropolitan regions[11].

Second, this study included 221 census-defined Metropolitan Statistical Area (MSAs). According to the United State Office of Management and Budget (OMB), they defined 381 Metropolitan Statistical Areas (MSAs) for the United States. They define MSAs as counties that have more than 50,000 population. Among 381 MSAs, the study

[10] Ewing et al. (2014) suggested the standard for selecting 994 counties.

[11] http://www.census.gov/

excluded counties with population less than 200,000 people because of the lack of data availability[12] and the reason that urban sprawl more relevant to larger cities. Thus 221 MSAs which include 994 counties, were used in this study (Figure 3).

In addition, this study used Census Regions to explore-specific variations in relationships between resilience and sprawl. The United States Census divides the country into four regions (figure 4): West, Midwest, South, and Northeast, and this study utilizes this scheme to assess the potential regional variations.

Figure 4. The United States Census Regions (source: www.ncdc.noaa.gov)

[12] In order to measure urban sprawl index by Ewing & Hanmidi (2014), at least two urban block groups are required for each county. Thus, the study excluded those counties that had only one block group. Also, counties that had no urban census tract (density greater than 100 person/sq. mi) were excluded.

3.5. Measurement

3.5.1. Urban Sprawl

1) Urban Sprawl Index

This study used the urban sprawl Index developed by Ewing & Hanmidi (2014b), a composite measure of features in urban area by measuring a wide variety of factors, including density, land use, centering, and street accessibility. His urban sprawl index includes four major components of urban form (Table 3).

The first is *Development Density* that is measured by the following five sub-factors: 1) population density in persons per square mile; 2) percentage of the county population living at low suburban densities – between 100 and 1,500 persons per square mile; 3) percentage of the county population living at medium to high urban densities – more than 12,500 persons per square mile); 4) net population density of urban places derived from estimated urban land area for each county from the National Resources Inventory of the United States Department of Agriculture; and 5) gross employment density in persons per square mile derived with employment data from the Local Employment Dynamics (LED) database rather than population data from the 2010 Census.

The second is *Land Use Mix* that is measured by three factors: 1) job-population balance between jobs and residents which is calculated for each block group using block-level population data from the 2010 Census, and block-level employment data from the 2010 LED database; 2) job-mixing calculated for each block group using retail, entertainment, health, education, and personal services sectors (values were weighted by the sum of block group population and employments as a percentage of the county total); and 3) Walk Score[13] measured by the countywide average walk score.

The third is *Activity Centering*, which indicates the percentage of residents living in the nearby business, measured by the following four factors: 1) population densities measured by the coefficient of variation in census block group population density which is defined as the standard deviation of block group densities divided by the average density of all block group using the 2010 census data; 2) employment densities measured by the coefficient of variation in census block group employment densities which is defined as the standard deviation of block group densities divided by the average density of all block groups using the Local Employment Dynamics (LED) database; 3) population in CBD measured by county population percentage in CBD; and 4) employment in CBD measured by the proportion of the county employment in CBD.

Lastly, it is *Street Accessibility* measured with four factors: 1) average block size with the exclusion of rural blocks which are larger than one square mile, 2) the small urban blocks percentage which is calculated by the percentage of block with area less than 1/100 square mile; 3) intersection density of census tracts which is calculated by the percentage of intersections within the county; and 4) the proportion of four or more way interactions out of total intersections.

[13] A walk score represents how easy it is to walk around neighborhood without car. The score means the walkability for a given location. The walk score data is provided by the Walk Score, Inc.

2) Data Source

Data collection was conducted at the county level. Using the Local Employment Dynamics (LED) database (available from 2002-2010), mix use and activity centering factors were collected. This database is established by the Census Bureau and the data offer unique features about local economic conditions. In this study, LED data were collected for the year 2010. Street factor was collected using the street centerline data from TomTom[14] with ArcGIS. The TomTom street dataset contains centerlines and intersections for each road section. Also, most of the indices is obtained from the 2010 United States Census data for each county (Table 3).

3) Measurement and Aggregation

The measurement of variables and data sources are shown in Table 3. Four components and sixteen variables were used to measure urban sprawl. After measuring each variable, the variables were normalized using Min-Max Normalization so that individual variables can be combined into a single composite variable to represent urban sprawl.

[14] TomTom is company (Dutch) that creates mapping and navigation products.

A value of 0 and 100 indicate, respectively, the most and least sprawling urban form. It should be noted that higher values in this index actually represents the lower levels of sprawl. This is a simple and commonly employed way to compare values measured with different scales or units of measure.

This study combined every indicator into one component using normalized score. For aggregation, this study gave an equally weighted value to each indicator, because this method is straight forward and easy to understand for combining indicators with different scales.

Also, according to the literature review by Cutter et al. (2010) and Ewing et al. (2014), there is no suitable theoretical support for the differential weights among the indicators. While there are methods for establishing weighting schemes, they tend to be subjective and they do not always show the precedence for decision makers (Esty et al. 2005).

Table 3. Urban Sprawl Indicators and Data Sources

Type	Variable	Definition	Data
Density Factor	Population density	Gross population in persons per square mile	2010 Census
	Low suburban densities	Percentage of the population living at low suburban densities	2010 Census
	Medium urban densities	Percentage of the population living at medium to high urban densities	2010 Census
	Net population Density	Urban population density based on the National Land Cover Database	2006 NLCD[3)]
	Employment density	Gross employment density of urban and suburban census tracts	2010 LED[1)]
Mix Use Factor	Job-population balance	Measures the countywide average degree of balance between jobs and residents	2010 Census
	Job mixing	Degree of job mixing which measures the countywide average degree of job mixing	2010 LED[1)]
	Walk Score	Walk score which measure the countywide average walk score	Walk score, Inc.
Centering Factor	Population densities	Coefficient of variation in census block group population densities	2010 Census
	Employment densities	Coefficient of variation in census block group employment densities	2010 LED[1)]
	Population in CBD	Percentage of county population in CBD	2010 Census
	Employment in CBD	Percentage of county employment in CBD	2010 LED[1)]
Street Factor	Block size	Average block size within the county	2010 Census
	Small urban blocks	Percentage of blocks with area less than one hundredth of a square mile	2010 Census
	Intersection density	Intersection density for census tracts within the county	TomTom (ESRI)[2)]
	≥4-way intersections	Percentage of 4-or-more-way intersections for census tracts within the county	TomTom (ESRI)[2)]

* Reference: Ewing et al. (2014), [1)] LED: Longitudinal Employment Dynamics Database [2)] TOMTOM: The TomTom dataset includes one centerline feature for each road segment running between neighboring intersections. [3)] NLCD: National Land Cover Data

3.5.2. Disaster Resilience

1) Disaster Resilience Measurement

Many researchers have developed various methods to construct indicators of disaster resilience. Also, most of the existing scientific research points to a theoretical construction for resilience which is related to a natural problem, such as preserving wetlands. Therefore, to measure disaster resilience, a theoretical framework should be developed for indicator selection, weighting, and aggregation (Nardo et al., 2005).

Among the various measurements[15] available from the previous literature, this study used the DROP (the disaster resilience of place) model that includes community, institutional, social, economic, and infrastructure components. This model suggests a basic process and framework of how to measure the disaster resilience, such as a guide of selecting indicators by each sector, measure of each indicator, and data aggregation including weighting.

The DROP model performs the relationship between resilience and vulnerability with the following characteristics: First, this model is theoretically grounded with an empirical testing process. Second, this model allows for a quantitative analysis. Third, it can address the problems in real places. Lastly, this model focuses on the antecedent condition[16] that is related to inherent resilience, such as social system, built environment, and product of place specific.

[15] See chapter 2.2.2 above.
[16] "Antecedent conditions represent a temporary state within dynamic natural and social systems that precedes and influences the onset and magnitude of a hazard and its consequences" (Crozier et al., 2013).

For choosing the DROP model, this study also considered the following criteria: 1) geographic scale and the smallest unit of analysis, whether it is possible to apply this model at the county level; 2) the main components of each component, whether it contains multiple dimensions of the environment, such as social, economic, infrastructure, institutional, and community aspect; and 3) the methodology, whether it contains numeric indicators and supports the use of secondary data.

Finally, this study attempts to measure an inherent disaster resilience by measuring disaster vulnerability and preparedness of place with the DROP model, rather than measuring disaster recovery rate in a damaged area using proxy or indicators of resilience.

2) Disaster Resilience Indicators

While there is no agreement on a recommended framework to guide the measurement of disaster resilience, a general consensus among the disaster resilience researchers is that resilience is a multifaceted concept and should be captured considering multiple perspectives, such as social, economic, institutional, infrastructural, and community factors. The DROP model also has similar multi-faceted approach. Thus, this study chose the disaster resilience indicators with a multifaceted concept drawing from the previous literature (Table 5).

Table 4. Disaster Resilience Indicators and Justification

Category	Indicator	Justification	Effect
Social Factors	Educational Equality	Morrow (2008), Norris et al. (2008)	Positive
	Elderly	Morrow (2008), Cutter et al. (2010)	Negative
	Communication Capacity	Morrow (2008), Cutter et al. (2010)	Negative
	Non-Disability	Cutter et al. (2010)	Positive
	Language Competency	NRC (2006), Susan et al. (2010)	Positive
	Racial/Ethnic Inequality	Tierney (2009), Susan et al. (2010)	Positive
Economic Factors	Homeownership	Wisner et al. (2004), Carpenter (2015)	Positive
	Employment	Norris et al. (2008), Cutter et al. (2010)	Positive
	Single Sector Employment	Carpenter (2015), Cutter et al. (2010)	Positive
	Female Employment	Morrow (2008), Cutter et al. (2010)	Positive
	Median House Income	Carpenter (2015), Mileti (1999)	Positive
	GINI Coefficient	Norris et al. (2008), Cutter et al. (2010)	Positive
	Poverty	Cutter et al. (2010), Carpenter (2015)	Negative
Infrastructure Factors	House Type	Sherrieb et al. (2012), Morrow (2008)	Positive
	House Age	Sherrieb et al. (2012), Cutter et al. (2010)	Positive
	Shelter Capacity	Tierney (2009), Morrow (2008)	Positive
	Transportation Assess	Mileti (1999), Carpenter (2015)	Positive
	Medical Capacity	Norris et al. (2008), Cutter et al. (2010)	Positive
Institutional Factors	Hazard Mitigation Plan	Vale (2005), Cutter et al. (2010)	Positive
	Disaster Experience	Colten et al. (2008), Morrow (2008)	Positive
	Storm Mitigation	Cutter et al. (2010)	Positive
Community Competence	Place Attachment	Norris et al. (2008),	Positive
	Political Engagement	Cutter et al. (2010)	Positive
	Physician Number	Morrow (2008), Sherrieb et al. (2012)	Positive
	Health Coverage	Tierney (2009), Cutter et al. (2010)	Positive

The indicators were selected by two reasons: 1) the relevance to resilience based on the literature, 2) the expediency of the data needed to capture the indicators, such as whether it is readily available from existing sources and whether it can be used at a county level. Also, proxy indicators were used for measuring resilience because it is difficult to measure the absolute value of the resilience.

There are five components in the selected disaster resilience indicators. Each component contains three to seven indicators and a total of 25 indicators were used in this study (Table 5). The first is Social Component that is measured by the following six sub-factors: 1) percentage of population with college education or more; 2) percentage of elderly population aged 65 or older; 3) percentage of population with no telephone service available; 4) percentage of population with disabilities; 5) percentage of population speaking English as a first language; and 6) percentage of population non-Hispanic or Latino.

The second is Economic Component that is measured by seven factors: 1) percentage of home ownership; 2) percentage of employed population; 3) percentage of population not-employed in fishing, farming, and extractive businesses; 4) percentage of female population with employment; 5) medium house income; 6) GINI coefficient[17]; and 7) percentage of population with poverty.

The third is Infrastructure Component captured with the following four factors: 1) percentage of non-mobile home units; 2) percentage of housing unit built after 2000; 3) percentage of vacant rental units; and 4) hospital beds number per 10,000 people.

The Fourth is Institutional Component measured with the four factors: 1) number of hazard mitigation plan projects within the county; 2) number of disaster declarations within the county; and 3) number of municipal expenditure projects within the county.

Lastly, it is Community Competence Component containing the following factors: 1) percentage of population born in the state (still live in that state); 2) engagement calculated by the number of voter participation; 3) physicians number per 100,000 populations; and 4) percentage of population with health insurance.

[17] "The GINI coefficient is a numerical statistic used to measure income inequality in a society (https://en.wikipedia.org/Gini coefficient)."

Table 5. Disaster Resilience Indicators and Data Source

Category	Variables	Description	Data
Social Factors	Educational Equality	Percent population with college education or more	Census 2014
	Elderly	Percent elderly population (more 65)	Census 2014
	Communication Capacity	Percent population with no telephone service available	Census 2014
	Non-Disability	Percent population without disabilities	Census 2014
	Language Competency	Percent population not speaking English as a second language	Census 2014
	Racial/Ethnic Inequality	Percent non-Hispanic or Latino	Census 2014
Economic Factors	Homeownership	Percent homeownership	Census 2014
	Employment	Percent employed population	Census 2014
	Single Sector Employment	Percent population not employed in farming, fishing, and extractive industries	Census 2014
	Female Employment	Percent female labor force population	Census 2014
	Median House Income	Median House Income	Census 2014
	GINI Coefficient	GINI Coefficient	Census 2014
	Poverty	Percent population with poverty	Census 2014
Infrastructure Factors	House Type	Percent housing units that are not mobile homes	Census 2014
	House Age	Percent housing units built after 2000	Census 2014
	Shelter Capacity	Percent vacant rental units	Census 2014
	Transportation Assess	Percent population with a vehicle	Census 2014
	Medical Capacity	Number of hospital beds per 100,000 population	City & County Book 2007
Institutional Factors	Hazard Mitigation Plan	Number of hazard mitigation plan projects	FEMA.gov
	Disaster Experience	Number of disaster declarations	FEMA.gov
	Municipal Service	Number of municipal expenditure projects	FEMA.gov
Community Competence	Place Attachment	Percent population born in a state that still resides in that state	Census 2014
	Political Engagement	Percent voter participation in the 2004 election	City & County Book 2007
	Physician Number	Number of physicians per 100,000 population	City & County Book 2007
	Health Coverage	Percent population with health insurance	Census 2014

3) Data Source

Most of the factors used to capture social, economic, infrastructure resilience were collected from the 2014 United States Census data[18] for each county. For institutional resilience, there are three variables. First of all, number of mitigation plan was collected from the FEMA website. They offer the dataset of "Hazard Mitigation Grants" from 1988 to 2010. This study used the total number of mitigation plan for each county. Secondly, this study used the dataset of "Disaster Declarations Summaries" from the FEMA website. The number of disaster declarations was collected from 1965 to 2009 (the total number of declaration). Lastly, the number of municipal expenditure was assembled using the dataset of "Public Assistance Funded Projects" from 1978 to 2008 (FEMA website). For the community competence resilience, "County and City Data Book: 2007[19]" was used to collect political engagement and physician number.

4) Measure and Aggregation

There are five components in the disaster resilience indicators. Each component contains several variables, and each variable was measured as shown in Table 5. Some indicators have a negative influence on disaster resilience, with higher values representing low levels of disaster resilience.

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[18] http://www.socialexplorer.com
[19] https://www.census.gov

To ensure a consistent direction of association with resilience, the order of all variables were examined and converted as needed to ensure that higher values represent higher levels of disaster resilience. The raw values were then normalized using Min-Max Normalization for combining every variable (Equation 1, see page 16). It means that a score of zero is the least resilient condition and score of 100 is the most resilient condition.

After normalizing the variables, the final step was to combine the individual factors into a single factor. This study gave an equally weight to every indicator to compute a single composite disaster resilience variable. There are many different ways to combine multiple variables but the equal weight method is simple, easy to understand, and popularly used especially when there is no strong theoretical rational exists to give varying weights. Further, the DROP model used the same approach and keeping the methods consistent was determined preferable (Cutter et al., 2010).

3.6. Correlation Analysis

This study used Pearson's product moment correlation analysis to examine the association between urban sprawl and disaster resilience. The value of the Pearson's coefficient ranges from -1 to 1, in which -1 represents the perfect negative or inverse linear relationship, and 1 stands for the perfect positive linear relationship. In this study, the data were analyzed in two phases.

First, this study performed correlation analyses in three aspects to compare disaster resilience with urban sprawl: 1) correlation analysis between individual factors of disaster resilience and urban sprawl index; 2) correlation analysis between sub-components of disaster resilience and sub-components of urban sprawl index; and 3) correlation analysis between overall score of disaster resilience and overall score of urban sprawl index.

Second, in order to analyze the differences in the resilience-sprawl relationship across different regions, this study used Census Regions in correlation analysis to explore region-specific variations in their relationships.

Also, this study analyzed the level of disaster resilience according to the gradient of urban compactness. For this purpose, the high, medium, and low sprawl areas were selected. Low compactness means counties lower than 90.5 sprawl index. Medium compactness indicates counties between 90.5 and 103.7 sprawl index, and high compactness refers to those higher than 103.7 sprawl index (Berrigan et al., 2014).

4. RESULTS

The research results are presented in three sections. The first section shows the descriptive statistics of urban sprawl and disaster resilience. The second section presents the relationship between urban sprawl and disaster resilience based on the Pearson correlation analysis. The last section shows the difference in the sprawl-resilience relationship across the four United States Census regions.

4.1. Descriptive Analysis Results

4.1.1. Urban Sprawl

1) Urban Sprawl Scores

This study used the urban sprawl index developed by Ewing et al. (2014) in order to evaluate the urban development patterns in the 994 study counties. These four factors are combined to calculate each area's Sprawl Index score (Table 6). Higher scores signify higher compactness. The scores ranged from 22 to 149 with the average index of about 95. We can derive from this result that the areas with the sprawl index value of 95 or higher have the above-average conditions for the compactness of urban development patterns. Geographic distribution of urban sprawl index values for the continental United States is shown in figure 5.

Table 6. Descriptive Statistic of Urban Sprawl Score

Category	Variables	Description	Mean	S.D	Min	Max
Density Factors	Population density	Total density of the urban and suburban census tracts;	96.96	7.28	88.03	654.01
	Low suburban densities	Percentage of the population living at low suburban densities				
	Medium urban densities	Percentage of the population living at medium to high urban densities				
	Net population Density	Urban density based on the National Land Cover Database				
Mix-use Factors	Job-population balance	Measures the countywide average degree of balance between jobs and residents	92.35	23.09	22.76	177.53
	Job mixing	Degree of job mixing which measures the countywide average degree of job mixing				
	Walk Score	Walk score which measure the countywide average walk score				
Centering Factors	Population densities	Coefficient of variation in census block group population densities	96.19	17.41	66.08	400.25
	Employment densities	Coefficient of variation in census block group employment densities				
	Population in CBD	Percentage of county population in CBD or sub-centers				
	Employment in CBD	Percentage of county employment in CBD or sub-centers				
Street Factors	Block size	Average block size excluding rural blocks of more than one square mile	98.24	22.34	40.96	230.03
	Small urban blocks	Percentage of small urban blocks of less than one hundredth of a square mile				
	Intersection density	Intersection density for urban and suburban census tracts within the county				
	4 way intersections	Percentage of 4-or-more-way intersections				
Urban Compactness (Composite)			94.86	18.88	45.49	425.15

2) Most and Least Sprawling Counties

Table 7 shows the ranking of ten most compact and ten most sprawling counties from the 994 study counties. The most compact counties are usually located in the central areas of old or large metropolitan area. On the other hand, the most sprawling counties are generally located in an outlying area of a large metropolitan area, or constituent area of smaller metropolitan areas.

Table 7. Most and Least Compact Counties

Rank	County	Urban Compact	Density	Mix-use	Center	Street
Most Compact Counties						
1	New York County, NY	425.15	654.01	144.57	400.25	230.33
2	Kings County, NY	265.2	355.5	142.16	199.99	225.25
3	San Francisco County, CA	251.27	250.84	153.79	258.47	215.72
4	Bronx County, NY	224.01	336.7	143.95	100.25	211.61
5	Philadelphia County, PA	207.19	206.38	144.48	178.43	209.98
6	District of Columbia, DC	206.37	193.52	138.05	219.97	185.15
7	Queens County, NY	204.16	266.34	147.42	91.93	224.01
8	Baltimore city, MD	190.94	163.61	143.97	183.84	196.44
9	Norfolk city, VA	179.57	129.98	131.46	210.96	179.44
10	Hudson County, NJ	178.73	223.23	156.67	92.82	176.49
Most Sprawling Counties						
1	Oglethorpe County, GA	45.49	88.61	22.76	70.81	45.28
2	Grant Parish, LA	53.79	88.67	34.23	66.17	64.67
3	Elbert County, CO	54.3	88.27	44.14	72.69	50.26
4	Macon County, TN	54.34	90.08	45.11	73.25	47.03
5	Harris County, GA	55.12	89.51	34.28	71.89	62.25
6	Greene County, NC	56.56	90.47	47.46	83.61	40.96
7	Blount County	56.6	90.36	37.85	74.28	60.14
8	Brown County, IN	58.47	92.73	36.11	76.3	63.42
9	Morrow County, OH	58.82	89.85	49.6	83.41	46.82
10	Spencer County, KY	60.36	91.13	31.97	75.02	76.42

4.1.2. Disaster Resilience

1) Disaster Resilience Scores

The descriptive statistics for each variable is provided in Tables 8 and 9. This study used these factors to evaluate disaster resilience index values of 994 counties. These five sub-components are combined by giving an equal weight to each variable, to generate a single composite resilience score for each county. In terms of the disaster resilience score, higher scores mean higher levels of resilience. The scores ranged from 172 to 315 with an average of 236.

In addition, the community competence resilience shows the greatest proportion of disaster resilience judging from its largest score (12.13[20]). It suggests that this component plays a more important role explaining the overall disaster resilience compared to other components.

Table 8. Descriptive Statistics of Disaster Resilience Sub-Components

Variables	Mean	S.D	Min	Max
Social Resilience	66.01	7.66	35.21	81.58
Economic Resilience	61.30	9.07	31.25	81.39
Infrastructure Resilience	46.18	9.73	16.94	69.23
Institutional Resilience	14.59	10.39	0.00	100.00
Community Competence	48.55	7.80	23.32	73.22
Disaster Resilience (Total)	236.65	22.86	172.57	315.61

[20] There are four indicators in this component and total score is 48.55 (48.55/4 = 12.13).

Table 9. Descriptive Statistics of Disaster Resilience Variables

Category	Variables	Description	Mean	S.D	Min	Max
Social Factors	Educational Equality	Percent population with college education or more	54.39	9.66	31.88	77.85
	Elderly	Percent elderly population (more 65)	85.88	5.18	64.00	96.72
	Communication Capacity	Percent population with a telephone (home)	96.62	1.31	90.76	100.00
	Non-Disability	Percent population without disabilities	13.55	3.02	6.39	20.25
	Language Competency	Percent population not speaking English as a second language	82.73	15.19	8.79	97.94
	Racial/Ethnic Inequality	Percent non-Hispanic or Latino	81.90	17.94	4.58	98.72
Economic Factors	Homeownership	Percent homeownership	68.73	9.58	28.06	85.51
	Employment	Percent employed population	90.45	2.77	81.65	96.08
	Single Sector Employment	Percent population not employed in farming, fishing, and extractive industries	92.52	3.14	73.47	96.26
	Female Employment	Percent female labor force population	90.52	2.88	79.22	96.87
	Median House Income	Median House Income	50799	11013	30953	88262
	GINI Coefficient	GINI Coefficient	.44	.03	.35	.54
	Poverty	Percent population with poverty	84.76	5.59	64.74	94.53
Infrastructure Factors	House Type	Percent housing units that are not mobile homes	87.22	8.79	60.30	99.51
	House Age	Percent housing units built after 2000	21.64	9.13	3.97	47.72
	Shelter Capacity	Percent vacant rental units	20.68	11.21	2.33	50.29
	Transportation Assess	Percent population with a vehicle	97.81	1.08	94.02	99.90
	Medical Capacity	Number of hospital beds per 10,000 population	245.52	174.63	29.00	1172
Institutional Factors	Hazard Mitigation Plan	Number of hazard mitigation plan project	16.84	29.24	.00	245.00
	Disaster Experience	Number of disaster declarations	16.18	7.32	.00	49.00
	Municipal Service	Number of municipal expenditure projects	176.94	479.28	.00	4587
Community Competence	Place Attachment	Percent population born in a state that still resides in that state	57.34	16.41	19.56	84.90
	Political Engagement	Percent voter participation in the 2012 election	123.74	917.82	4.21	11586
	Physician Number	Number of physicians per 10,000 population	192.02	143.10	1.00	890.00
	Health Coverage	Percent population with insurance health	81.65	4.27	64.26	90.74

2) Most and Least Resilient Counties

Table 10 provides a list of ten most and ten least resilient counties in the United States. The ten most resilient counties are usually located in or near metropolitan areas (except Lincoln, Cass, and Orange counties). On the other hand, the ten least resilient counties are usually in rural areas. The Harris County (TX) had the highest disaster resilience and the Yuma County (AZ) shows lowest disaster resilience.

Table 10. Most and Least Resilient Counties

Rank	County	Resilience Score	Social	Eco-nomic	Infra	Insti-tute	Com-munity
Most Resilient Counties							
1	Harris County, TX	321.03	67.89	61.25	72.28	80.59	39.03
2	Jefferson County, KY	318.06	75.42	62.42	61.26	61.87	57.09
3	Delaware County, OH	317.45	88.21	80.25	73.35	21.58	54.07
4	Jefferson Parish, LA	309.65	71.18	63.07	59.87	61.87	53.67
5	Lincoln County, SD	308.83	88.94	78.37	79.88	12.69	48.96
6	Fayette County, KY	307.76	89.98	77.47	76.61	15.67	48.03
7	Chester County, PA	303.68	82.73	74.71	63.90	27.81	54.53
8	Cass County, ND	302.57	85.85	67.21	69.34	29.53	50.64
9	Westchester County, NY	300.79	80.29	75.03	66.06	18.20	61.21
10	Orange County, NC	300.70	85.21	67.60	63.93	33.42	50.54
Least Resilient Counties							
1	Yuma County, AZ	183.16	51.58	46.59	47.58	1.69	35.72
2	Imperial County, CA	186.67	76.62	31.14	57.94	1.54	19.44
3	Terrell County, GA	188.92	44.63	39.45	56.14	6.02	42.68
4	Mineral County, WV	193.73	53.37	39.88	44.70	7.70	48.08
5	Anson County, NC	198.57	61.37	40.18	39.60	6.69	50.72
6	Murray County, GA	199.96	62.24	40.28	42.16	1.54	53.74
7	Webb County, TX	201.35	50.95	53.47	47.38	8.23	41.31
8	Morgan County, WV	201.36	66.64	41.68	35.24	4.71	53.09
9	Tulare County, CA	201.80	65.73	51.25	40.86	3.93	40.03
10	Mohave County, AZ	202.13	42.89	55.62	60.80	8.16	34.66

3) Geographic distribution of Disaster Resilience and Urban Sprawl

The geographic distribution for the continental United States is shown in the figures 5 and 6. Overall, while sprawling areas have low disaster resilience, compact areas have high resilience. It is apparent especially in the Middle Atlantic and Pacific regions. This geographic distribution are further confirmed in the results of correlation analysis (See the Chapter 4.2.2).

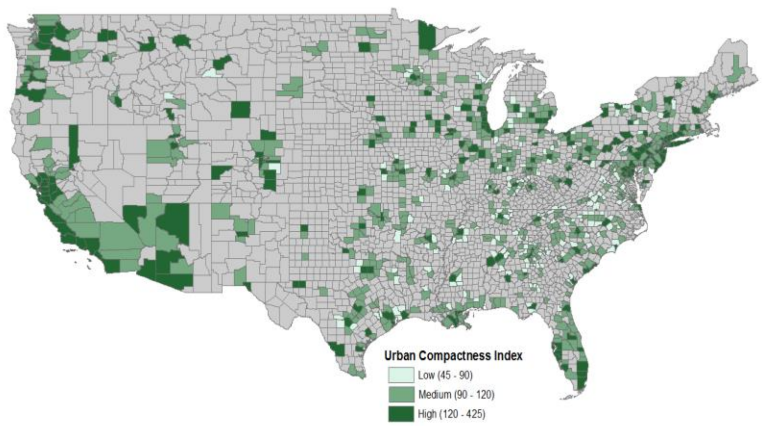

Figure 5. County Level Distribution of Urban Compactness

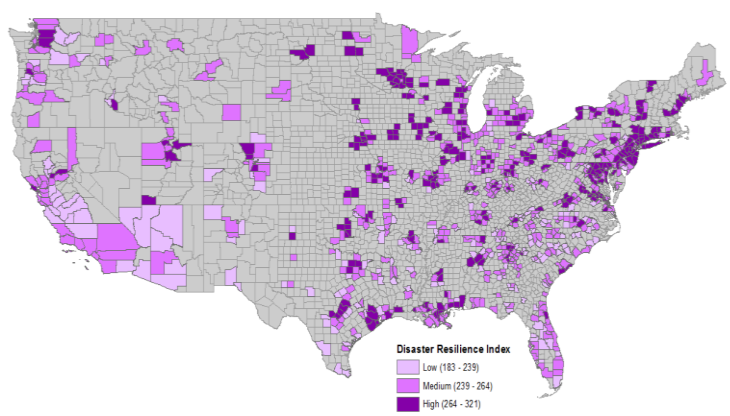

Figure 6. County Level Distribution of Disaster Resilience

4) Characteristic of Disaster Resilience according to Urban Compactness

This study analyzed the characteristics of disaster resilience with regards to urban sprawl/compactness. While the mean of disaster resilience values in the high compact area is 259.84, the mean of the disaster resilience in the low compactness (meaning high sprawl) area is 249.72. In other words, less sprawled and more compact areas tend to have higher disaster resilience. Similar patterns of association was found with urban sprawl for infrastructure resilience and institutional resilience (Table 11).

Table 11. Characteristic of Disaster Resilience by Urban Sprawl Level*

	Urban Sprawl Index		
Mean (SD)	High Compactness (n=156)	Medium Compactness (n=490)	Low Compactness (n=347)
Disaster Resilience (Total)	259.84 (19.85)	256.40 (20.12)	249.72 (18.91)
Social Resilience	74.12 (7.04)	73.93 (7.51)	73.60 (5.93)
Economic Resilience	62.27 (7.15)	62.45 (7.01)	62.77 (7.05)
Infrastructure Resilience	58.67 (6.58)	56.99 (6.80)	54.06 (8.87)
Institutional Resilience	13.89 (11.07)	10.97 (6.78)	9.11 (5.75)
Community Resilience	50.86 (8.50)	50.03 (7.64)	50.17 (6.94)

* Low compactness means lower than 90.5 sprawl index. Medium compactness means counties between 90.5 and 103.7 sprawl index, and high compactness means higher than 103.7 sprawl index. The lager the urban sprawl index, the more compact (Berrigan et al., 2014).

This study also used a one-way ANOVA test for the characteristics of disaster resilience with regard to urban sprawl/compactness. This model has the significance probability of <0.001 and F-value of 12.121. Thus, this model is statistically significant meaning that the level of disaster resilience is significantly different across different levels (high, medium and low) of urban sprawl/compactness. In addition, the mean of disaster resilience in the high and medium compactness areas is significantly higher than that of low compactness area, while the disaster resilience values between the high and medium compactness areas do not differ significantly. It can be interpreted that disaster resilience is significantly lower in high sprawl (low compactness) areas, compared to the areas with medium-to-low levels of sprawl (Table 12).

Table 12.One-way ANOVA test by Urban Sprawl Level

		Urban Sprawl Index				
		High Compactness (n=171, A)	Medium Compactness (n=424, B)	Low Compactness (n=375, C)	F	p-value
Disaster Resilience	Mean (SD)	259.31 (19.85)	254.68 (20.12)	247.42 (18.91)	12.121***	<.001
	Scheffe	A . B > C				

*** $p < 0.01$

4.2. Correlation Analysis Results

4.2.1. Relationship between Urban Sprawl and Disaster Resilience

1) Relationship between Urban Sprawl and Individual Resilience Indicators

The study performed correlation analysis between urban sprawl index and each of the disaster resilience indicators (Table 13). Most of the indicators have significant positive or negative coefficient, indicating some meaningful relationships between urban sprawl and each resilience indicator.

Among the disaster resilience indicators, a mobile home (house type) that decreases disaster resilience has the strongest relationship with the urban sprawl index, meaning that there are more mobile homes in sprawling area and that this mobile home is related to decrease of resilience. Also, high levels of education, more vacant rental units, number of population with a vehicle, and the number of hospital beds per 10,000 population were positively correlated with urban compactness. It tells us that these factors are higher in compact areas and contribute to increase disaster resilience.

Especially, the number of hazard mitigation, municipal expenditure projects for disaster, and disaster experience, all of which are positively related to disaster resilience, were higher in compact areas.

On the other hand, home-ownership positively associated with disaster resilience, has the strongest negative relationship with urban compactness. It suggests that the rate of homeownership is higher in sprawling areas. In addition, the number of people with disabilities, those speaking English as a second language, and the number of Hispanic/Latino were higher in compact areas. It means that these demographic and socioeconomic characteristics of the community should be taken into consideration when promoting disaster resilience in sprawling areas.

On the whole, while the institutional resilience and infrastructure resilience indicators have a positive effect on urban compactness, social resilience and community resilience indicators are negatively associated with urban compactness (positively with urban sprawl).

Table 13. Correlation Analysis between Urban Compactness and Individual Disaster Resilience Factors

	Urban Sprawl Index				
Disaster Resilience indicators	Density Factor	Mix-Use Factor	Centering Factor	Street Factor	Urban Compactness (Composite)
Social Resilience					
Educational Equality	.429**	.432**	.230**	.247**	.378**
Age (more than 65)	.126	.047	-.009	-.189*	-.040
Community Capacity	-.027	-.006	-.074	-.044	-.044
Non-Disability	-.462**	-.354**	-.205**	-.094	-.288**
Language Competency	-.538**	-.421**	-.270**	-.478**	-.486**
Racial/Ethnic Inequality	-.362**	-.330**	-.195*	-.413**	-.383**
Economic Resilience					
Homeownership	-.534**	-.575**	-.461**	-.388**	-.566**
Employment	-.011	.060	-.081	.017	.004
Single Sector Employment	.147	.018	.114	-.054	.038
Female Employment	-.038	.024	-.071	.015	-.010
Median House Income	.026	-.051	-.128	-.178*	-.120
GINI Coefficient	.447**	.519**	.495**	.481**	.579**
Poverty	-.091	-.147	-.194*	-.159*	-.184*
Infrastructure Resilience					
House Type	.652**	.704**	.399**	.423**	.626**
House Age	-.036	-.149	.011	-.209**	-.137
Shelter Capacity	.461**	.467**	.318**	.218**	.411**
Transportation Assess	.437**	.416**	.424**	.385**	.481**
Medical Capacity	.249**	.443**	.377**	.362**	.447**
Institutional Resilience					
Hazard Mitigation Plan	.567**	.389**	.277**	.487**	.482**
Previous Disaster Mitigation	.273**	.321**	.259**	.497**	.418**
Municipal Service	.208**	.184*	.168*	.255**	.241**
Community Competence					
Place Attachment	-.469**	-.337**	-.271**	-.345**	-.395**
Political Engagement	-.077	-.038	-.050	.033	-.026
Physician Number	.524**	.615**	.484**	.458**	.614**
Health Coverage	-.265**	-.233**	-.172*	-.353**	-.304**

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Table 14. Disaster Resilience Indicators Significantly Associated with Urban Compactness/Sprawl

	Relationship with Urban Compactness		
	Positive (+)	Negative (-)	Not Significant
Social Resilience	*Educational Equality***	*Non-Disability***	*Age (Less than 65)*
	-	*Language Competency***	*Community Capacity*
	-	*Racial/Ethnic Inequality***	-
Economic Resilience	*GINI Coefficient***	*Homeownership***	*Employment*
	-	*Poverty***	*Single Sector*
	-	-	*Employment*
	-	-	*Female Employment*
	-	-	*Median House Income*
Infrastructure Resilience	*House Type***	*Transportation Assess***	*House Age*
	*Shelter Capacity***	-	-
	*Medical Capacity***	-	-
Institutional Resilience	*Hazard Mitigation Plan***	-	-
	*Previous Experience***	-	-
	*Municipal Service***	-	-
Community Resilience	*Physician Number***	*Place Attachment***	*Political Engagement*
	-	*Health Coverage***	-

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Table 14 summarizes correlation analysis results of urban compactness and individual resilience factors, according to its positive, negative, or no relationship. As previously described, positive relationships are found between infrastructure and institutional resilience with urban compactness, while negative relationships are found for social, community resilience. From these results, one may infer as following:

First, drawing from the findings on two positive resilience indicators, disaster resilience in sprawling area can be approved by considering the following: 1) policies to address inequality in education and income levels in sprawling areas; 2) improving access to healthcare by increasing the density of hospital beds and physicians in sprawling areas; 3) policies addressing vulnerability to natural disaster in urban areas through strategies like a comprehensive disaster mitigation plan. The last point was based on the finding that in compact areas, institutional factors, e.g., hazard mitigation, previous disaster experience, and municipal support, were high, which may be due to the possibility that while vulnerability to natural disaster is high in urban area, the degree of preparedness may also be high, resulting in increased inherent resilience to disaster.

Second, we need to pay attention to counterintuitive and negative relationship between certain resilience indicators and compactness. The following considerations may offer relevant insights to improve disaster resilience: 1) higher proportion of people with disabilities, of Hispanic and Latino origin, and with poverty are found in sprawling areas. Thus, disaster related policies targeting those in poverty, with disability and who are of Hispanic origin living in sprawling areas may be an important priority. 2) For the health insurance indicator, it has a negative relationship with urban compactness. Thus, strategies to increase the health insurance policy coverage and tackling the underlying contributors related to low health insurance coverage of residents living in compact areas appear important for increasing disaster resilience.

Third, several resilience indicators do not show any statistically significant with urban sprawl. This suggests that there is no meaningful difference between sprawling and urban areas with regards to the specific resilience indicators related to age, telephone usage, employment, median income, and house age. It may also be because of the relatively small variation/standard deviation in (range of) these variables, as seen in table 14.

2) Relationship between Urban Sprawl and Sub-Domains of Resilience

This section reports the findings from the correlation analyses between the sub-components of disaster resilience including social, economic, infrastructure, institutional, and community competence resilience, and sub-components of urban sprawl including density, mixed-use, centering and street factors (Table 15). According to the result, while the social resilience and the community competence have a negative relationship with urban compactness, the infrastructure and the institutional resilience have a positive association with urban compactness (negative with urban sprawl index) at the 0.01 level. Furthermore, the coefficient of disaster resilience has a positive relationship (0.186) with urban compactness significant at the 0.01 level. It means that disaster resilience would be higher in less sprawling areas.

Also while urban compactness and its sub-components have same/similar directions of association across different each sub-component of disaster resilience, different disaster resilience sub-component variables have inconsistent directions of association with the sub-components urban sprawl index.

Table 15. Correlations Analysis between Urban Compactness and Disaster Resilience Sub-components

	Urban Sprawl Index				
	Density Factor	Mix-Use Factor	Centering Factor	Street Factor	Urban Compactness (Composite)
Social Resilience	-.338**	-.249**	-.200*	-.359**	-.330**
Economic Resilience	-.003	-.021	-.083	-.057	-.054
Infrastructure Resilience	.419**	.467**	.299**	.178*	.385**
Institutional Resilience	.418**	.365**	.287**	.510**	.466**
Community Competence	-.276**	-.090	-.078	-.210**	-.170*
Disaster Resilience (Total)	.160*	.242**	.131*	.093	.186**

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

3) Relationship between Urban Sprawl and Disaster Resilience

This study conducted an unadjusted regression analysis using the total disaster resilience score and urban sprawl index (Table 16). The result shows that there is a statistically significant ($p<0.001$) relationship between urban sprawl and disaster resilience. Their relationship is positive, indicating that compact areas have higher disaster resilience.

Table 16. Bivariate analysis between Urban Compactness and Disaster Resilience

Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	R^2	F	D-W[a]
	B	Std. Error	Beta					
(Constant)	225.799	2.00	-	112.917	.000	0.186	34.163*	1.768
Urban Compact	.232	.039	.184	5.892	.000			

Dependent Variable: Disaster Resilience, * p<.000, a: Durbin-Watson

The total disaster resilience score has a limitation to measure the disaster resilience because sub-components of resilience have different directions of association. Thus, this study used the unadjusted regression analysis using the sub-components of disaster resilience and urban sprawl index to verify their association, not to draw causal relationships between urban sprawl and resilience (Table 17). The result shows that there is a statistically significant ($p<0.001$) relationship between urban sprawl and sub-components of disaster resilience with the exception of the community resilience component. Infrastructure and institutional resilience components are positive, indicating that compact areas have higher disaster resilience.

Table 17. Regression Analysis between Urbans Compactness and Sub-Components of Resilience.

Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.t	VIF
	B	Std. Error	Beta			
(Constant)	56.347	4.787		11.771	.000	
Social Resilience	**-.720**	**.045***	-.308	-11.040	.000	1.375
Economic Resilience	**-.369**	**.050***	-.185	-7.397	.000	1.135
Infrastructure Resilience	**.825**	**.036***	.444	18.051	.000	1.088
Institutional Resilience	**.699**	**.023***	.396	16.133	.000	1.027
Community Competence	-.167	.121	-.180	-1.131	.000	1.394

Y: Urban Compactness, * $p<0.05$, a: Durbin-Watson, $R^2 = 0.672$, $F= 162.71$, D-W^a = 1.573

4.2.2. Difference in Relationship by Different Regions

This study uses a correlation analysis to explore regional differences (based on United States Census Regions) in the sprawl-resilience relationship across the United States. The coefficient value of each region is statistically significant correlation with urban compactness. In particular, the Northeastern region has the strongest relationship (0.300) between urban compactness and disaster resilience. This result may be due to its dense population and more urbanized development patterns among the four regions. According to the 2013 US Census Bureau estimate, the population density of Northeast region is 345.5 people per square mile, 2.5 times as high as the second-most dense region (the South). On the other hand, the Western region shows the weakest relationship (0.129), and it may be due to the region's sparsely settlement patterns with 49.5 inhabitants per sq. mile. The Western region also is inhabited by the greatest number of minority populations in the United States, which is related to its lower social resilience found in this study. The Southern region, the second densest region, shows the second strongest relationship (0.237) between resilience and sprawl. These results signify that the disaster-sprawl relationships vary across the United States Census Regions, and it supports the hypothesis that increase in population density is positively correlated with resilience (Table 19).

Table 18. Descriptive Statistics of the United States Census Regions

Variable	West Region	Midwest Region	South Region	Northeast Region
Total Population	73,627,351	67,353,303	117,320,439	55,805,991
Land Area (sq. miles)	1,751,053	750,522	868,417	161,911
Population Density (per sq. mile)	42.0	89.7	135.1	344.7
Income	$57,641	$51,882	$49,656	$60,501
Education less than High School	7,240,307 (15.0%)	4,859,634 (10.8%)	11,837,615 (15.2%)	4,650,192 (12.2%)
Age more than 65	9,347,329 (12.7%)	9,514,629 (14.1%)	16,102,824 (13.7%)	8,213,179 (47.7%)
Hispanic/Latino	21,444,685 (29.1%)	4,894,035 (7.3%)	19,333,816 (16.5%)	7,397,560 (13.3%)
Employment	33,038,937 (57.2%)	31,754,92 (59.6%)	52,024,832 (56.2%)	26,616,544 (59.0%)

Table 19. Relationship between Urban compactness and Disaster Resilience by US Census Regions

Census Divisions	-	Mean	Min	Max	Correlation Analysis
West Region (N=118)	Disaster Resilience	244.08	183.16	289.82	**.129***
	Urban Compactness	111.54	54.30	251.27	
Midwest Region (N=226)	Disaster Resilience	258.18	202.13	321.03	**.191****
	Urban Compactness	93.77	68.57	177.33	
South Region (N=525)	Disaster Resilience	252.68	186.67	318.06	**.237****
	Urban Compactness	95.50	45.49	190.94	
Northeast Region (N=121)	Disaster Resilience	265.05	193.73	303.68	**.300****
	Urban Compactness	114.94	69.28	425.15	

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Figure 7 shows these associations with a graph. The relationship between urban sprawl and disaster resilience varies in different areas of the US with a most positive association in the Northeast region and least positive association in West region.

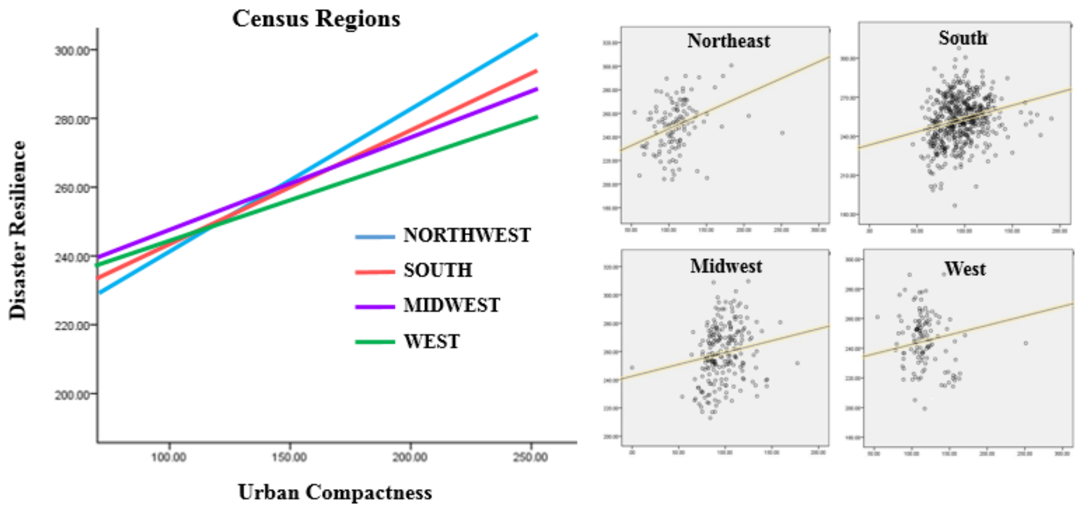

Figure7. Relationship Graph between Urban compactness and Disaster Resilience by US Census Regions

This study also performed a correlation analysis by different regions using sub-component of disaster resilience (social, economic, infrastructure, institutional, and community capacity resilience). The remarkable thing is that infrastructure and institutional resilience show the strongly positive relationship with urban compactness in the Northeastern region. Also, the Northeastern region has the strongly negative correlation between social resilience and urban compactness. While each sub-component has different directions relationship, their relationships with different regions have similar results with the relationship between total disaster resilience and urban compactness (Table 20).

Table 20. Correlation Analysis by Census Regions

Census Divisions	Disaster Resilience	Correlation Analysis
West Region (N=118)	Social Resilience	**-.114****
	Economic Resilience	-.117
	Infrastructure Resilience	.015
	Institutional Resilience	**127****
	Community Competence	**-.138****
Midwest Region (N=226)	Social Resilience	**-.073****
	Economic Resilience	124
	Infrastructure Resilience	**263****
	Institutional Resilience	**.266****
	Community Competence	-.072
South Region (N=525)	Social Resilience	**-.182****
	Economic Resilience	.032
	Infrastructure Resilience	**.346****
	Institutional Resilience	**.176****
	Community Competence	-.063
Northeast Region (N=121)	Social Resilience	**-.298****
	Economic Resilience	**-.284****
	Infrastructure Resilience	**.379****
	Institutional Resilience	**.127****
	Community Competence	-.114

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

5. DISCUSSION AND CONCLUSIONS

This chapter summarizes important findings from the study, discussing the implications for disaster planning. Study limitations and conclusions are also included in this section.

5.1. Discussion

5.1.1. Summary of Key Findings

This study was designed 1) to describe the relationship between urban sprawl and disaster resilience based on a count-level correlational analysis, and 2) to verify if such a relationship varied across the four United States regions. The two main outcomes of this studies are discussed below.

First, the results show that sub-components of disaster resilience have different directions of association with urban sprawl. While the infrastructure and institutional resilience components have a negative association with urban sprawl, the community and social resilience components are positively related with urban sprawl (negatively with urban compactness). It means that counties with more sprawling developments should pay particular attention to infrastructure and institutional factors related to disaster planning.

Also, each disaster resilience indicator has a statistically significant association with urban sprawl. Some indicators, such as high level of education, vacant rental units, vehicle ownership, and the number of hospital beds per 10,000 population are negatively correlated with urban sprawl. On the other hand, other indicators, such as the number of people with disabilities, homeownership, population speaking English as the second language, and the number of Hispanic/Latino population, are positively associated with urban sprawl.

Furthermore, the correlation analysis shows there is a negative relationship between urban sprawl and disaster resilience at the 0.01 level. This finding indicates that disaster resilience is higher in more compact counties. This result supports the recent research that showed positive relationships between urban compactness and disaster resilience (Carpenter, 2015). Also, the research by Lambert et al. (2015) is related to this study showing that urban sprawl, as a considerable amount of research claims, is an impact factor influencing the FEMA's assistance spending which is related to disaster resilience. In addition, some studies show associations with this study showing that compact city indicators, such as walkability, mixed use, and neighborhood are related to strengthen community resilience (Talen, 2002; Bansal et al., 2012; Taniguchi et al., 2005).

Second, the relationship between urban sprawl and disaster resilience varies across different regions. Among the four U.S Census regions, the Northeastern region including the Middle Atlantic and New England regions has the strongest relationship between urban compactness and disaster resilience, and the Western region including the Pacific and Mountain regions shows the weakest relationship. The Southern region (the West South Central East South Central and South Atlantic regions) shows the second strongest relationship between resilience and sprawl.

5.1.2. Planning Implications

The results of this study can offer insights to local planning and policy decision makers, in terms of how urban land use and infrastructure planning may influence different aspects of disaster resilience. They may be used to guide the development of hazard mitigation plans and management of development permit review system.

Findings from this study suggest that local governments should first determine high priority areas and populations for disaster planning purposes, also considering that high priority target may differ across different aspects of resilience considering the social, economic, infrastructure, institutional and community competence factors. Infrastructure and institutional factors appear to be more important in less sprawling areas to improve disaster resilience. Compared to the other resilience factors which are primarily related to socio-economic characteristics, such factors like infrastructure and institutional factors may be easier to intervene and improve with relevant county-level policy and planning efforts.

In addition, local governments should consider individual disaster resilience indicators for disaster planning. In compact areas, institutional resilience factors, e.g., hazard mitigation, previous disaster experience, and municipal support, were seen to be high. It means that the degree of preparedness for disaster is high in compact areas, while vulnerability to natural disaster is also high. This preparedness is related to increasing inherent resilience to disaster. Thus, for sprawling areas, we need to pay attention to ways to increase resilience through disaster mitigation plans. Policies to reduce vulnerability to natural disaster appear important in improving overall disaster resilience in urban areas.

5.2. Limitations

The limitations of this study include the use of county as the unit of analysis. Variables needed for this study were not available at a smaller geographic unit such as census block or neighborhood level, which could have led to more in-depth and localized investigation of the sprawl-resilience relationships. More longitudinal studies assessing pre and post disaster conditions, and long-term trends in sprawl-resilience relationships appear important. This is a simple correlation study without the use of longitudinal data, so no casual relationships between sprawl and urban resilience can be drawn. This study is an exploratory analysis and further study will be necessary with smaller geographic units and more detailed built environmental data are needed to further the understanding of disaster-sprawl relationships.

5.3. Conclusions

This paper is an exploratory study to assess the potential relationship between urban sprawl and disaster resilience. The outcome of this study supports the hypothesis that lower levels of urban sprawl (higher level of compactness) is linked to higher levels of resilience. Particularly, there are different results between sub-components of resilience and sprawl; the infrastructure and institutional resilience domains have a negative association with urban sprawl, while social and community competence resilience have a positive relationship. Also each disaster resilience indicator has different result of the relationship with urban sprawl. In addition, while this study suggests a significant relationship between sprawl and resilience, their relationship varies across different regions.

There are ample studies on the relationship built environment and resilience. However, little empirical work has been done on the relationship between urban sprawl and disaster resilience. This exploratory study examined the relationship between the built environment and resilience, and revealed that different directions of disaster-sprawl relationships across different disaster sub-domains and different magnitude of associations across different US regions, providing useful insights to guide future research on this important and timely topic.

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APPENDIX

Regression Analysis between Urbans Compactness and Each Indicator of Resilience

Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	VIF
	B	Std. Error	Beta			
(Constant)	77.602	19.268		4.027	.000	
Social Resilience						
Educational Equality*	**.398**	.077	.238	5.200	**.000**	3.634
Elderly	-.061	.047	-.017	-.522	.552	1.258
Communication Capacity	-.128	.085	-.038	-1.504	.133	1.442
Non-Disability	.070	.092	.035	.763	.446	**4.806**
Language Competency*	**.293**	.171	.133	2.014	**.027**	**7.326**
Racial/Ethnic Inequality*	**-.333**	.146	-.152	-2.280	**.023**	**7.914**
Economic Resilience						
Homeownership*	**-.228**	.116	-.108	-1.967	**.049**	3.737
Employment	-.045	.114	-.024	-.393	.694	**7.944**
Single Sector Employment	.104	.063	.043	1.653	.099	1.502
Female Employment	.289	.192	.086	1.497	.135	**7.392**
Median House Income	.026	.118	.012	.218	.828	**7.149**
GINI Coefficient*	**.235**	.116	.108	2.167	**.037**	**3.438**
Poverty*	**.346**	.108	.181	3.201	**.001**	**7.127**
Infrastructure Resilience						
House Type*	**.320**	.053	.212	6.095	**.000**	2.683
House Age*	**-.189**	.051	-.111	-3.665	**.000**	2.050
Shelter Capacity	-.031	.057	-.016	-.542	.588	1.948
Transportation Assess*	**2.306**	.154	.500	14.942	**.000**	2.483
Medical Capacity*	**.162**	.088	-.072	2.571	**.012**	1.981
Institutional Resilience						
Hazard Mitigation Plan*	**.309**	.124	.074	2.494	**.013**	1.944
Disaster Experience*	**.143**	.058	-.062	2.474	**.014**	1.380
Municipal Service*	**.075**	.103	-.022	3.275	**.001**	1.929
Community Resilience						
Place Attachment	-.007	.043	-.005	-.166	.869	2.125
Political Engagement	-.005	.103	-.002	-.047	.962	3.046
Physician Number	.039	.079	.018	.498	.618	2.908
Health Coverage*	**-.743**	.081	-.359	-9.180	**.000**	3.392

Dependent Variable: Urban Compactness, * $p<0.05$, a: Durbin-Watson, $R^2 = 0.751$, $F= 56.87$, D-W^a = 1.145